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(54) **PHOTOELECTRIC CONVERSION DEVICE AND MANUFACTURING METHOD THEREOF**

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(Continued)

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CPC H01L 31/02168; H01L 31/02363; H01L 31/0682; H01L 31/022441
USPC 136/256, 255, 252; 438/71, 72
See application file for complete search history.

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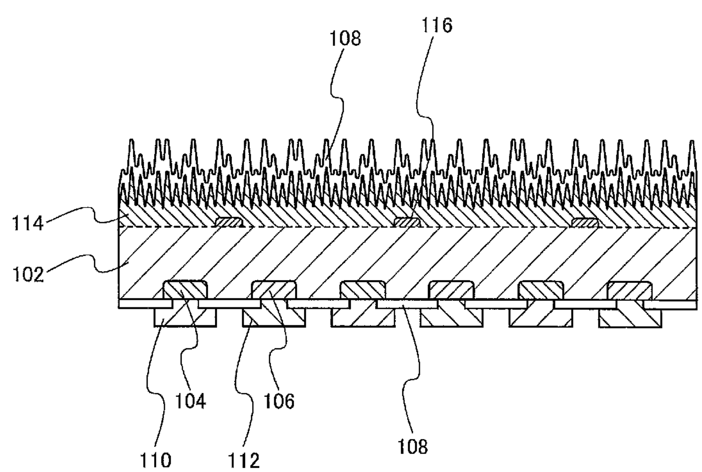
(57) **ABSTRACT**

A photoelectric conversion device with a novel anti-reflection structure. In the photoelectric conversion device, a front surface of a semiconductor substrate which serves as a light-receiving surface is covered with a group of whiskers (a group of nanowires) so that surface reflection is reduced. In other words, a semiconductor layer which has a front surface where crystals grow so that whiskers are formed is provided on the light-receiving surface side of the semiconductor substrate. The semiconductor layer has a given uneven structure, and thus has effects of reducing reflection on the front surface of the semiconductor substrate and increasing conversion efficiency.

16 Claims, 7 Drawing Sheets



(51) **Int. Cl.**
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Taiwanese Office Action re Application No. TW 100120886, dated May 20, 2015.

FIG. 1A

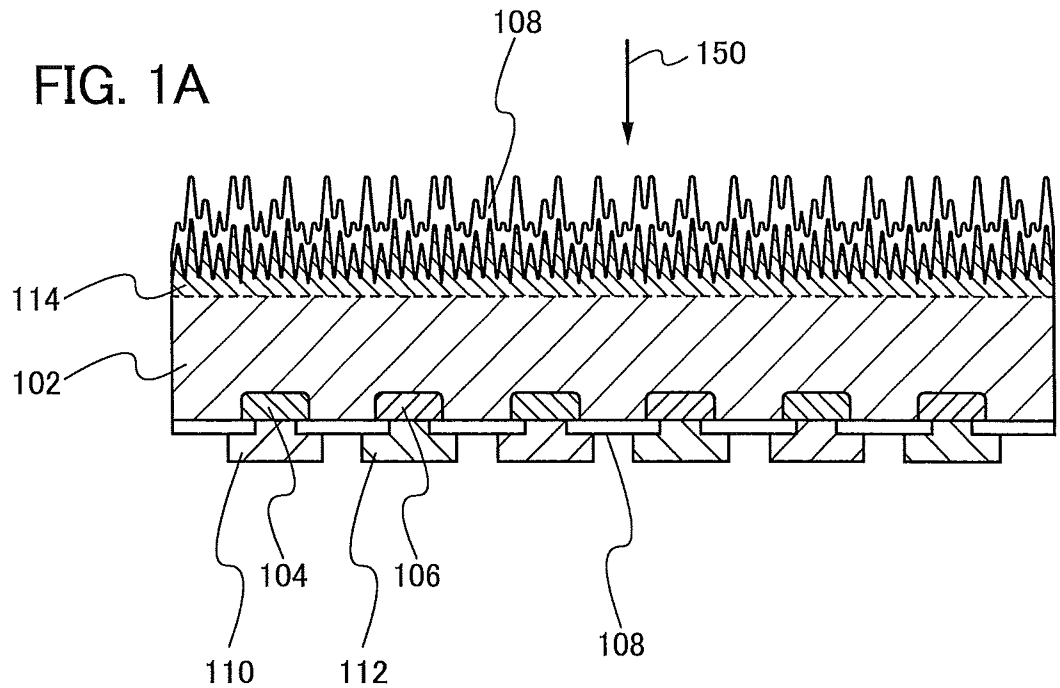


FIG. 1B

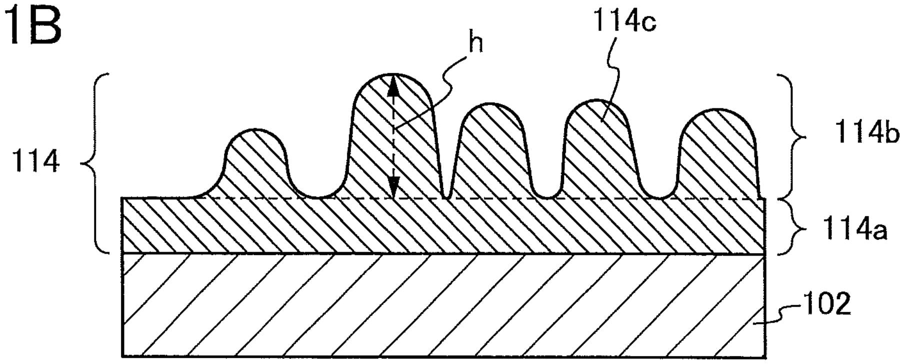


FIG. 1C

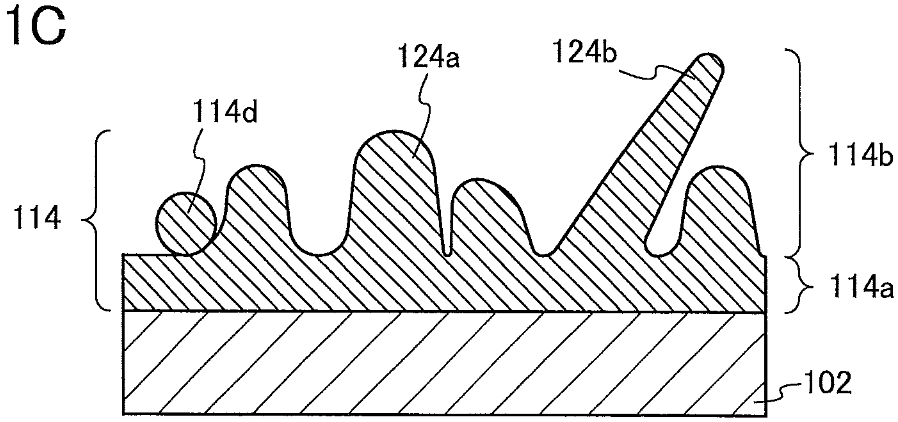


FIG. 2A

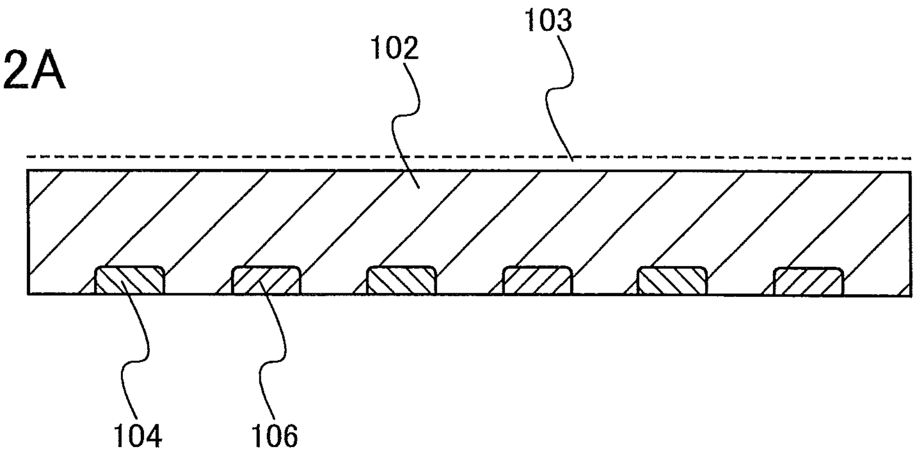


FIG. 2B

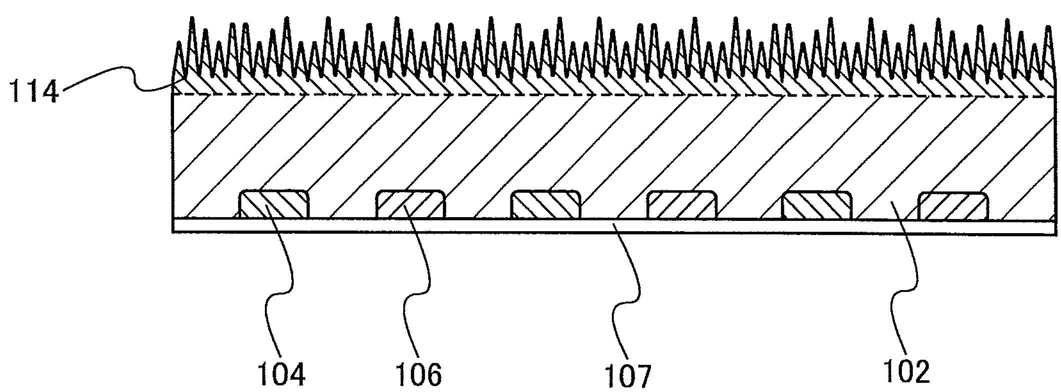


FIG. 2C

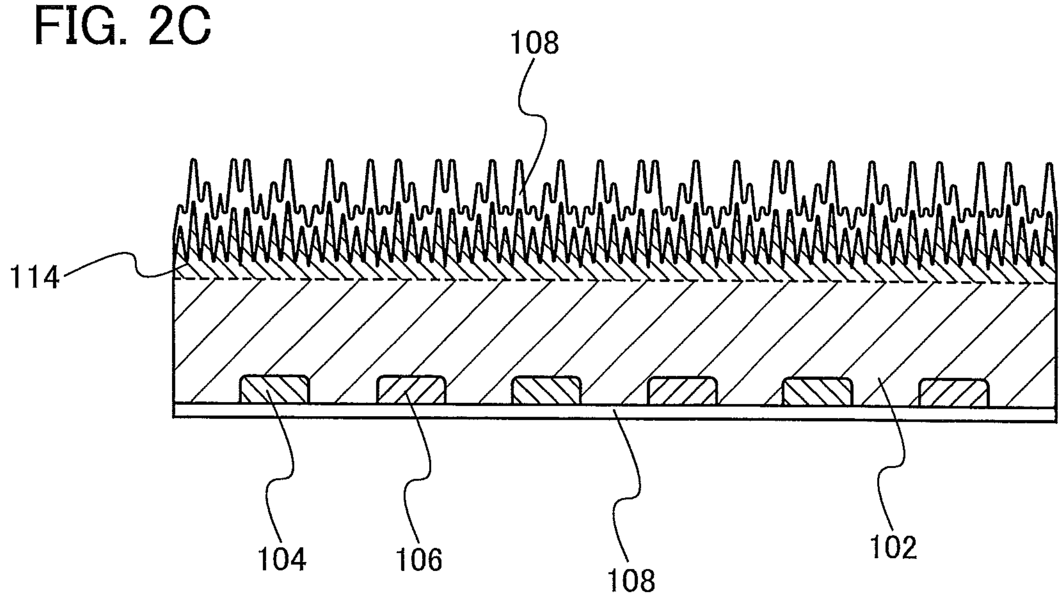


FIG. 3A

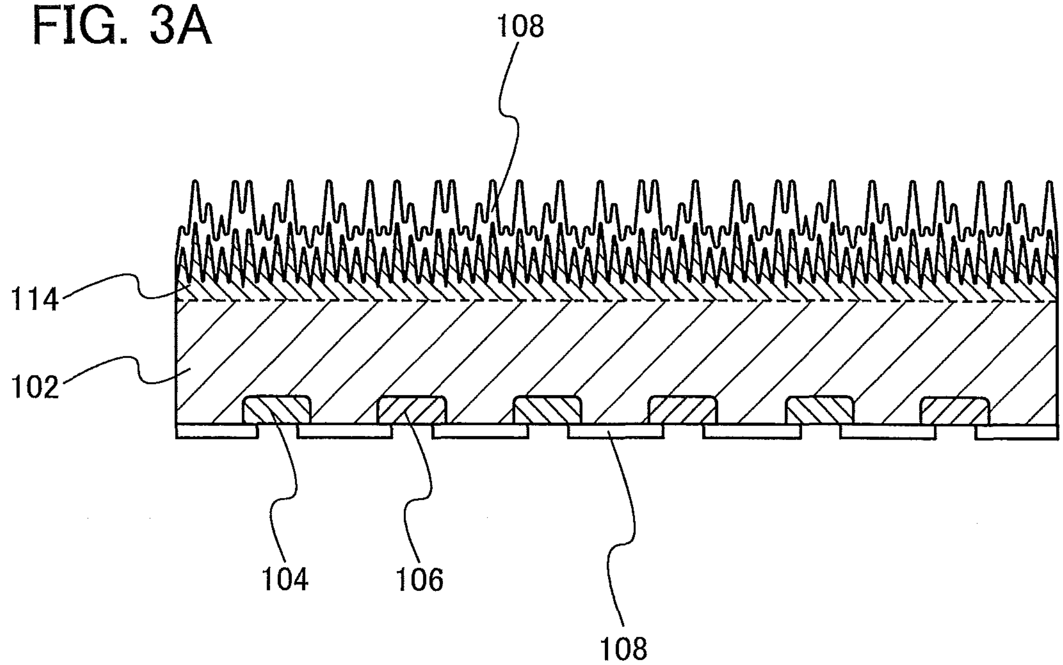


FIG. 3B

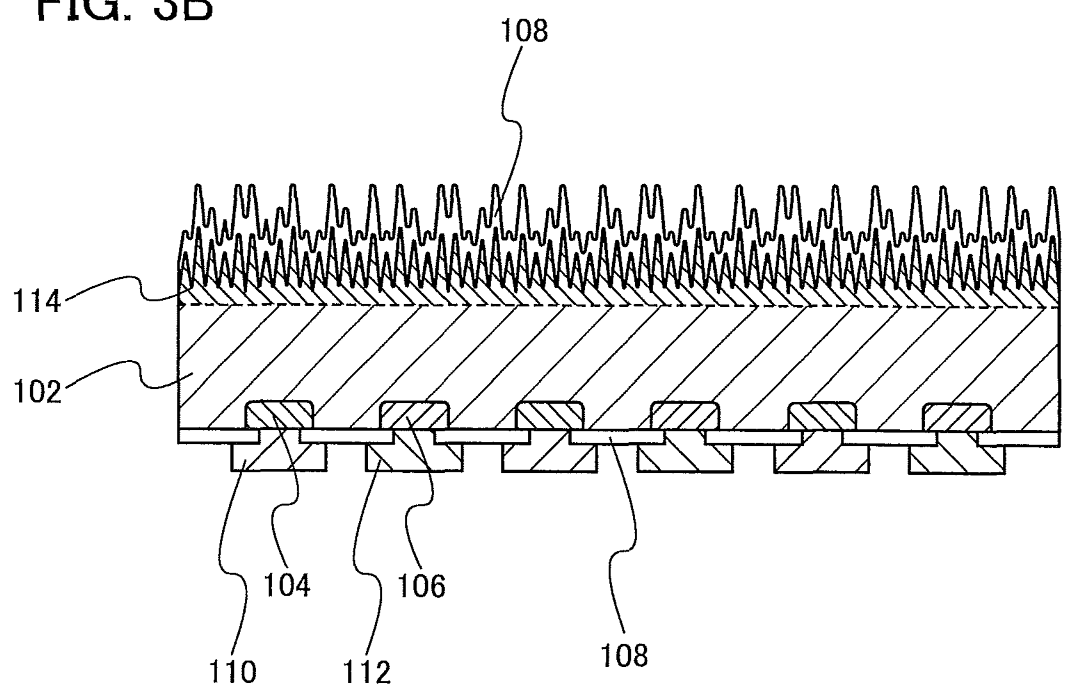


FIG. 4

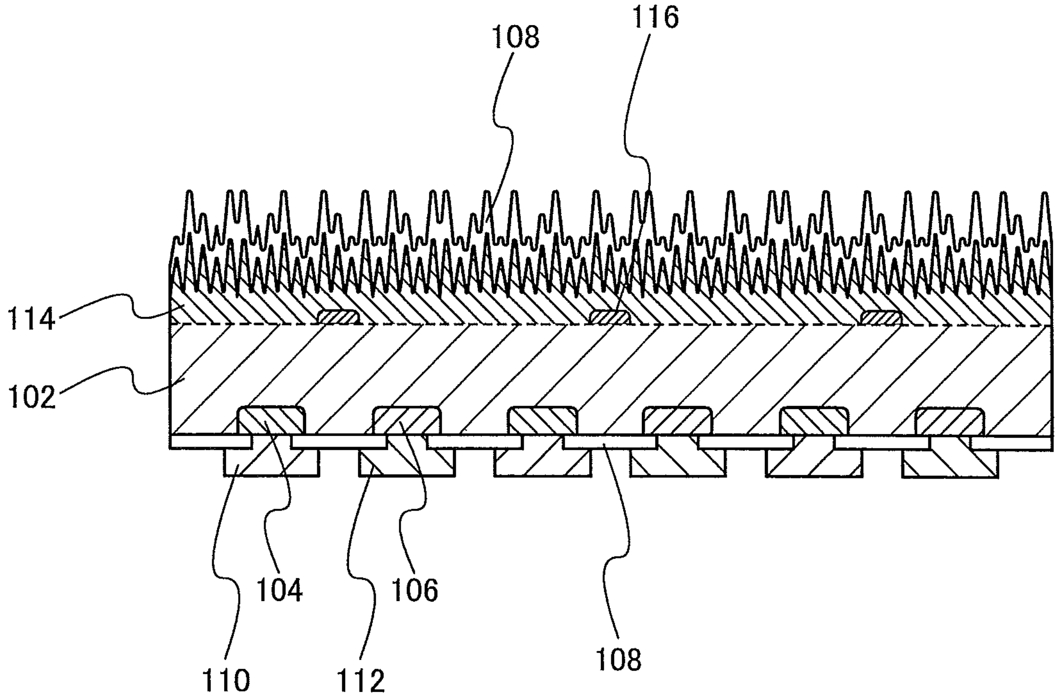


FIG. 5

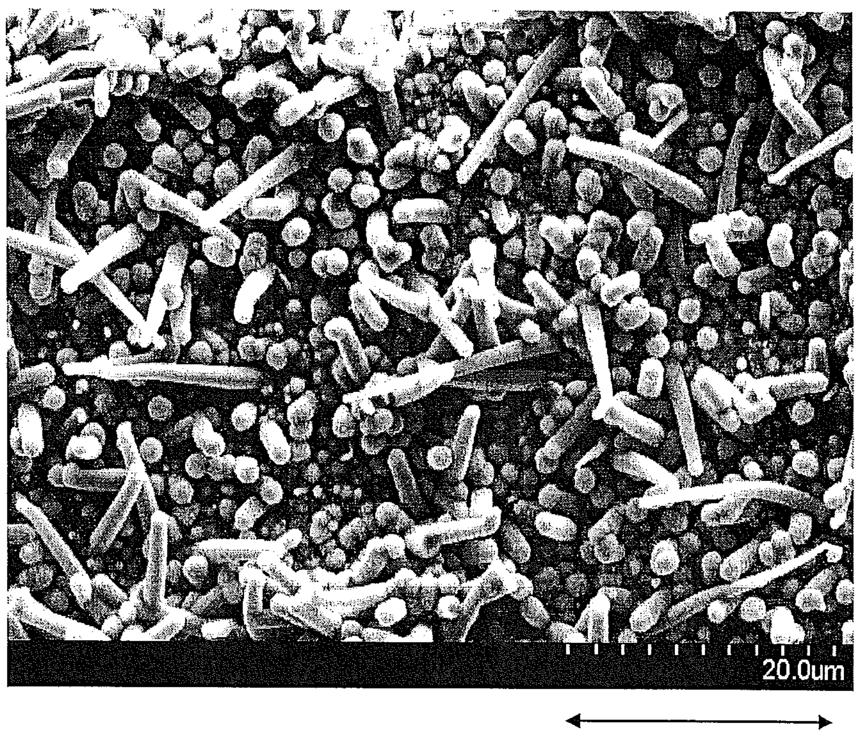
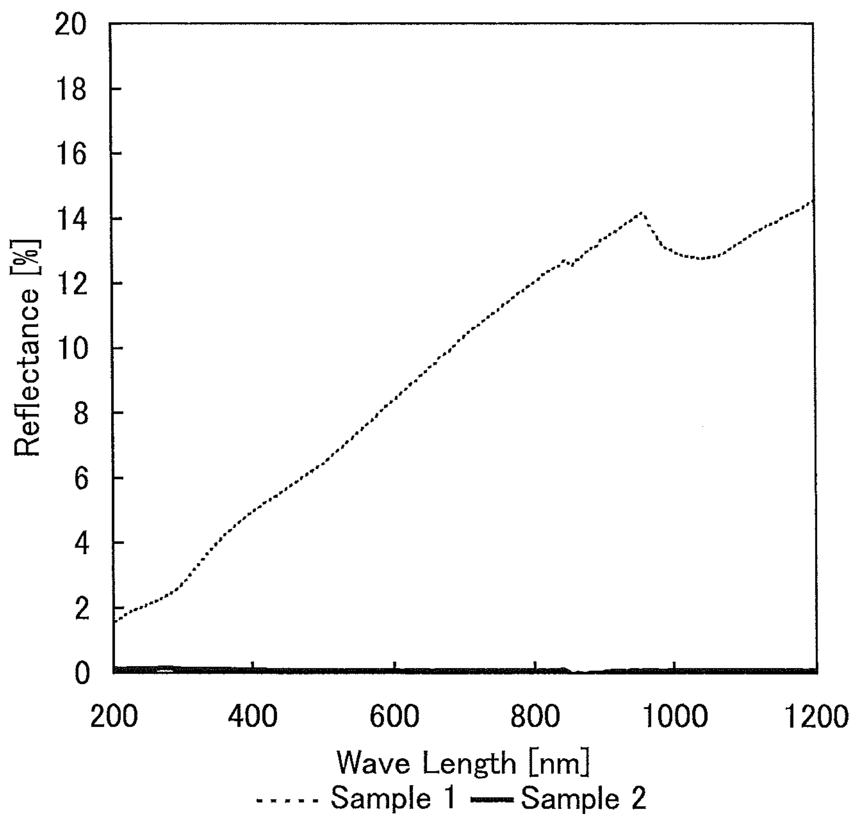


FIG. 6



20
18
16
14
12
10
8
6
4
2
0
Reflectance [%]
200
400
600
800
1000
1200
Wave Length [nm]
Sample 1
Sample 2

FIG. 7A

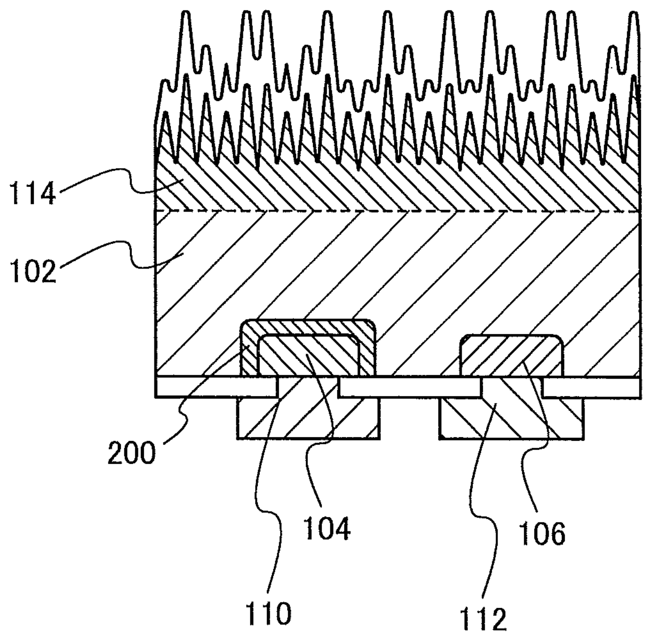
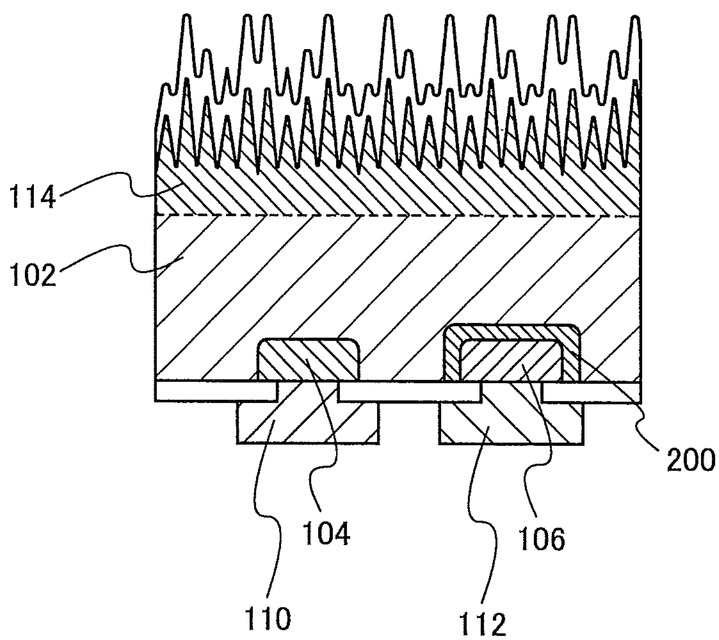


FIG. 7B



PHOTOELECTRIC CONVERSION DEVICE AND MANUFACTURING METHOD THEREOF

This application is a divisional of U.S. application Ser. No. 13/161,947, filed on Jun. 16, 2011 which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a photoelectric conversion device. One embodiment of the disclosed invention includes a back contact element structure.

2. Description of the Related Art

A solar cell in which a single crystal silicon substrate or a polycrystalline silicon substrate is used for a photoelectric conversion layer has been developed as one of photoelectric conversion devices. In such a solar cell, an uneven structure is formed on a front surface of the silicon substrate in order to reduce surface reflection. This uneven structure is formed by etching the silicon substrate with an alkaline solution such as NaOH. An alkaline solution has different etching rates depending on crystal plane orientations of silicon. Thus, for example, when a silicon substrate which has a crystal plane orientation of (100) is etched, a pyramidal uneven structure is formed. Back contact solar cells which have such an uneven structure have been proposed (e.g., Patent Document 1 and Patent Document 2).

However, etching with an alkaline solution contaminates a silicon substrate, and thus is not suitable. In addition, etching characteristics greatly vary depending on the concentration or temperature of an alkaline solution, which makes it difficult to form an uneven structure with high reproducibility. In view of the above, a method in which etching with an alkaline solution and a laser processing technique are combined has been proposed (e.g., Patent Document 3).

However, even by the method disclosed in Patent Document 3, it is difficult to form an uneven structure by etching, for example, in the case where a thin film is used as a photoelectric conversion layer.

[Reference]

[Patent Document 1] Japanese Published Patent Application No. 2002-164556

[Patent Document 2] Japanese Published Patent Application No. 2006-080450

[Patent Document 3] Japanese Published Patent Application No. 2003-258285

SUMMARY OF THE INVENTION

Etching a photoelectric conversion layer itself in order to form the above uneven structure is not preferable for the following reasons: a problem with controllability for the uneven structure is caused and the characteristics of a solar cell are adversely affected. Moreover, an alkaline solution and a large amount of rinse water is needed for the etching; thus, attention needs to be paid to contamination. For that reason, such etching is not preferable also in terms of productivity.

In view of the above, an object of one embodiment of the present invention is to provide a photoelectric conversion device with a novel anti-reflection structure.

A semiconductor surface which serves as a light-receiving surface is covered with a group of whiskers (also referred to as nanowires) so that surface reflection is reduced. In other words, a semiconductor layer with a front surface where

crystals grow so that whiskers are formed is provided on the light-receiving surface side of a semiconductor substrate. The semiconductor layer has a given uneven structure, and thus has an effect of reducing reflection on the front surface of the semiconductor substrate.

One embodiment of the present invention is a photoelectric conversion device. The photoelectric conversion device includes a semiconductor substrate; a group of whiskers which is formed of a crystalline semiconductor and is provided on a front surface of the semiconductor substrate; an n^+ region and a p^+ region which are provided on the back surface side of the semiconductor substrate; a first electrode which is electrically connected to the n^+ region; and a second electrode which is electrically connected to the p^+ region.

Another embodiment of the present invention is a photoelectric conversion device. The photoelectric conversion device includes a semiconductor substrate; a group of whiskers which is formed of a crystalline semiconductor and is provided on a front surface of the semiconductor substrate; an n^+ region and a p^+ region which are provided on the back surface side of the semiconductor substrate; a first electrode which is electrically connected to the n^+ region; a second electrode which is electrically connected to the p^+ region; and an insulating film which is provided on the group of whiskers.

Note that whiskers are formed in such a manner that crystals of a semiconductor material grow so as to have column-like protrusions or needle-like protrusions on the front surface of the semiconductor substrate.

Further, the n^+region is an n-type impurity region (also referred to as an n-type region) in which impurity elements imparting n-type conductivity are contained at high concentration; the p^+ region is a p-type impurity region (also referred to as a p-type region) in which impurity elements imparting p-type conductivity are contained at high concentration. Note that the term “high concentration” means the case where the carrier density of each region is higher than the carrier density of the semiconductor substrate.

The semiconductor layer which is grown so as to have whiskers as described above functions as an anti-reflection layer. Thus, light loss due to reflection on a light-receiving surface can be reduced and conversion efficiency can be increased.

Further, when an uneven structure on a light-receiving surface is formed with the use of a special semiconductor coating film which is grown by vapor deposition without etching with an alkaline solution unlike a conventional method, contamination of a semiconductor substrate can be prevented and productivity can be increased.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A to **1**C illustrate structures of a photoelectric conversion device.

FIGS. **2**A to **2**C illustrate a manufacturing method of a photoelectric conversion device.

FIGS. **3**A and **3**B illustrate the manufacturing method of the photoelectric conversion device.

FIG. **4** illustrates a structure of the photoelectric conversion device.

FIG. **5** shows structures of whiskers.

FIG. **6** shows reflectance of whiskers.

FIGS. **7**A and **7**B illustrate structures of the photoelectric conversion device.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention disclosed will be described below with reference to the drawings. However, the present invention is not limited to the following description, and it is easily understood by those skilled in the art that the modes and details of the present invention can be changed in various ways without departing from the spirit and scope of the present invention. Therefore, the present invention disclosed should not be construed as being limited to the description in Embodiments below.

In Embodiments hereinafter described, the same parts are denoted with the same reference numerals throughout the drawings. Note that the thickness, the width, a relative position, and the like of components, that is, layers, regions, and the like illustrated in the drawings are exaggerated in some cases for clarification in the description of the embodiments.

(Embodiment 1)

In this embodiment, structural examples of a photoelectric conversion device will be described.

FIGS. **1**A to **1**C illustrate structural examples of a photoelectric conversion device.

The photoelectric conversion device includes a semiconductor substrate **102** and receives light from the front surface (also referred to as light-receiving surface) side of the semiconductor substrate **102**. In one embodiment of the present invention, the photoelectric conversion device has an uneven structure for reducing reflection of incident light **150** on a front surface of the semiconductor substrate **102**. The structure will be specifically described below.

A group of whiskers **114** is formed on the front surface of the semiconductor substrate **102** as the uneven structure. The group of whiskers **114** can reduce surface reflection of the incident light **150** on the light-receiving surface. The group of whiskers **114** will be specifically described below.

FIG. **1**B is an enlarged view of the group of whiskers **114**.

As illustrated in FIG. **1**B, the group of whiskers **114** includes a crystalline semiconductor region **114***a* which covers the semiconductor substrate **102** and a whisker-like crystalline semiconductor region **114***b* which is formed over the crystalline semiconductor region **114***a*. The whiskers are formed in such a manner that crystals of a semiconductor material (e.g., silicon) grow so as to have column-like or needle-like protrusions **114***c*. The group of whiskers **114** has a plurality of the column-like or needle-like protrusions **114***c*.

Here, an interface between the crystalline semiconductor region **114***a* and the crystalline semiconductor region **114***b* is not clear. Therefore, the plane that is at the same level as the bottom of the deepest valley of the valleys formed among the protrusions **114***c* and is parallel to the front surface of the semiconductor substrate **102** is regarded as the interface between the crystalline semiconductor region **114***a* and the crystalline semiconductor region **114***b*.

Examples of the specific shape of the protrusion **114***c* include a column-like shape such as a cylindrical shape or a prismatic shape, a needle-like shape such as a conical shape or a polygonal pyramid shape, and the like. The top of the protrusion **114***c* may be rounded. The diameter of the protrusion **114***c* is greater than or equal to 50 nm and less than or equal to 10 μm, preferably greater than or equal to 500 nm and less than or equal to 3 μm. The length h along the axis of the protrusion **114***c* is greater than or equal to 0.5 μm and less than or equal to 1000 μm, preferably greater than or equal to 1.0 μm and less than or equal to 100 μm.

Note that the length h along the axis of the protrusion **114***c* is the distance between the top (or the center of the top surface) of the protrusion **114***c* and the crystalline semiconductor region **114***a* along the axis running through the top (or the center of the top surface) of the protrusion **114***c*.

Further, the thickness of the group of whiskers **114** is the sum of the thickness of the crystalline semiconductor region **114***a* and the thickness of the crystalline semiconductor region **114***b*. Here, the thickness of the crystalline semiconductor region **114***b* is the length of the line which perpendicularly runs from the top of the protrusion **114***c* to the crystalline semiconductor region **114***a* (i.e., the height of the protrusion **114***c*).

Further, the diameter of the protrusion **114***c* is the length of a long axis in a transverse cross-sectional shape of the protrusion **114***c* at the interface between the crystalline semiconductor region **114***a* and the crystalline semiconductor region **114***b*.

Note that the direction in which the protrusion **114***c* extends from the crystalline semiconductor region **114***a* is referred to as a longitudinal direction and the cross-sectional shape along the longitudinal direction is referred to as a longitudinal cross-sectional shape. In addition, the shape of the plane normal to the longitudinal direction is referred to as a transverse cross-sectional shape.

In FIG. **1**B, the longitudinal directions of the protrusions **114***c* extend in one direction, for example, in the direction normal to the front surface of the crystalline semiconductor region **114***a*. Note that the longitudinal direction of the protrusion **114***c* may be substantially the same as the direction normal to the front surface of the crystalline semiconductor region **114***a*. In that case, it is preferable that the difference in angle between the two directions be typically within 5°. The longitudinal direction of the protrusion **114***c* is substantially the same as the direction normal to the front surface of the crystalline semiconductor region **114***a* as described above; therefore, FIG. **1**B illustrates only the longitudinal cross-sectional shape of the protrusions **114***c*.

As another example, the longitudinal directions of a plurality of protrusions may vary as illustrated in FIG. **1**C. Typically, the crystalline semiconductor region **114***b* may include a first protrusion **124***a* whose longitudinal direction is substantially the same as the normal direction and a second protrusion **124***b* whose longitudinal direction is different from the normal direction. Moreover, the length along the axis of the second protrusion **124***b* may be greater than the length along the axis of the first protrusion **124***a*. The longitudinal directions of the plurality of protrusions vary as described above; therefore, the longitudinal cross-sectional shapes of the protrusions and the transverse cross-sectional shape of the protrusion (i.e., a region **114***d*) coexist in FIG. **1**C.

Optical characteristics of such a group of whiskers will be described with reference to FIG. **6**. FIG. **6** is a graph showing the wavelength dependence of regular reflectance of a titanium foil and a sample including a group of silicon whiskers having a polycrystalline structure on the titanium foil.

A sample **1** whose reflectance is represented by a dotted line in FIG. **6** is a titanium foil which is cut in a circle with a diameter ϕ of 12 mm and has a thickness of 0.1 mm. In addition, a sample **2** whose reflectance is represented by a solid line is formed in such a manner that a polysilicon layer including a group of whiskers is formed over the titanium foil with a diameter ϕ of 12 mm and a thickness of 0.1 mm, which are similar to those of the sample **1**, by an LPCVD method. The polysilicon layer here is formed by introducing silane for deposition for 2 hours and 15 minutes at a flow rate of 300 sccm into a process chamber in which the pressure is set to 13 Pa and the substrate temperature is set to 600° C.

The regular reflectance was measured by a spectrophotometer (U-4100 Spectrophotometer, manufactured by. Hitachi High-Technologies Corporation). Here, the samples **1** and **2** were irradiated with light having wavelengths from 200 nm to 1200 nm with a sampling interval of 2 nm. In addition, the reflectance was measured under the condition that the angle of incident light on each sample was 5° (i.e., 5-degree regular reflectance was measured). The horizontal axis represents the wavelength of the irradiation light and the vertical axis represents the reflectance of the irradiation light.

According to FIG. **6**, the sample **2** in which the polysilicon layer including the group of whiskers is formed on the surface of the titanium foil has an extremely low reflectance as can be seen from its regular reflectance of 0% to 0.15%, which means that there is almost no light reflection. Note that since the SN ratio is small in the wavelength range of 850 nm to 894 nm, the reflectance is negative. In contrast, the sample **1** that is the titanium foil has a regular reflectance of 2% to 15%. The results show that the reflectance can be reduced by forming the polysilicon layer including the group of whiskers on the surface of the titanium foil.

As is clear from the characteristics shown in FIG. **6**, when the group of whiskers **114** is provided, the surface reflectance of visible light in the entire wavelength range can be reduced to be less than or equal to 10%, preferably less than or equal to 5%.

An n^+ region **104** and a p^+ region **106** are formed on the back surface side of the semiconductor substrate **102**. In addition, an electrode **110** and an electrode **112** are formed on the n^+ region **104** and the p^+ region **106**, respectively. Note that a p-type substrate is used as the semiconductor substrate **102**.

In other words, a photoelectric conversion element including the electrode **110**, the n^+ region **104**, the p-type semiconductor substrate **102**, the p^+ region **106**, and the electrode **112** is formed on the back surface side of the semiconductor substrate **102**. The photoelectric conversion device has one or more of the photoelectric conversion elements. Here, the p-type semiconductor substrate **102** (also referred to as a p region) serves as an active layer.

Thus, according to one embodiment of the photoelectric conversion device, electrical contacts are made on the back surface (the surface opposite to the light-receiving surface). The photoelectric conversion device has a so-called back contact structure. Note that without limitation to the back contact structure, the photoelectric conversion device may have a group of whiskers on the light-receiving surface, as described above.

Note that an insulating film **108** may be formed on a back surface of the semiconductor substrate **102**. In that case, through contact holes formed in the insulating film **108**, the n^+ region **104** and the electrode **110** are electrically connected to each other, and the p^+ region **106** and the electrode **112** are electrically connected to each other.

Silicon or germanium is typically used for the semiconductor substrate **102**. Alternatively, a compound semiconductor such as gallium arsenide or indium phosphide may be used. Note that a single crystal semiconductor substrate or a polycrystalline semiconductor substrate can be used as the semiconductor substrate **102**. For example, the p-type semiconductor substrate contains an impurity element imparting p-type conductivity, such as boron. Note that an n-type semiconductor substrate may be used; for example, a substrate which contains an impurity element imparting n-type conductivity, such as phosphorus, is used. In addition, a substrate in a plate form or a thin film form can be used as the semiconductor substrate **102**.

Further, a p^- region **200** may be provided between the p-type semiconductor substrate **102** (p region) and the n^+ region **104** so that an $n^+/p^-/p/p^+$ structure in which the impurity concentration varies in the active layer is formed (FIG. **7**A). This structure allows the diffusion length of minority carriers to be increased by an internal electric field generated in the p^- region; thus, short-circuit current can be increased.

Alternatively, a p^- region **200** may be provided between the p-type semiconductor substrate **102** (p region) and the p^+ region **106** so that an $n^+/p/p^-/p^+$ structure in which the impurity concentration varies in the active layer (FIG. **7**B) is formed. This structure allows a high-resistant p^- region to be provided between the p region and the p^+ region and an energy difference between the active layer and the p^+ region to be increased; thus, open voltage can be increased. Further, an n^- region may be provided between the n^+ region and the p-type semiconductor substrate.

Note that the short-circuit current is current at the time when the voltage applied to the outside is 0 V and the open voltage is voltage at the time when the current flowing to the outside is 0 A. Each of the short-circuit current and the open voltage is one of the characteristics for determining the performance of a solar cell. The performance of a solar cell can be improved by increasing the short-circuit current and the open voltage.

Further, the n^+ region **104** is an n-type impurity region (also referred to as an n-type region) in which impurity elements imparting n-type conductivity are contained at high concentration; the p^+ region **106** is a p-type impurity region (also referred to as a p-type region) in which impurity elements imparting p-type conductivity are contained at high concentration. Further, an n^- region is an n-type impurity region in which impurity elements imparting n-type conductivity are contained at low concentration; a p^- region is a p-type impurity region in which impurity elements imparting p-type conductivity are contained at low concentration. Note that the term "high concentration" means the case where the carrier density of each region is higher than the carrier density of the semiconductor substrate **102**, whereas the term "low concentration" means the case where the carrier density of each region is lower than the carrier density of the semiconductor substrate **102**.

This embodiment can be combined with any of the other embodiments as appropriate.

(Embodiment 2)

In this embodiment, an example of a manufacturing method of a photoelectric conversion device will be described.

A metal layer **103** is formed on the front surface (a light-receiving surface) of the semiconductor substrate **102** (FIG. **2**A).

Here, a p-type single crystal silicon substrate is used as the semiconductor substrate **102**. Note that an n-type substrate may be used.

It is preferable that the metal layer **103** be formed to have an extremely small thickness of approximately several nanometers. The extremely small thickness of the metal layer **103** makes it possible to suppress absorption or reflection of incident light from the front surface of the semiconductor substrate **102** by the metal layer **103**. Here, the thickness of the metal layer **103** is greater than or equal to 1 nm and less than or equal to 10 nm.

Further, it is preferable that metal materials contained in the metal layer **103** be dispersed homogeneously in the front surface of the semiconductor substrate **102** and be held.

The metal layer **103** is formed by a sputtering method or the like with the use of a metal material typified by platinum, aluminum, copper, titanium, or an aluminum alloy to which silicon, titanium, neodymium, scandium, molybdenum, or the like is added. Note that a metal material which forms suicide by reacting with silicon is preferably used. When the metal layer **103** becomes silicide, light reflection can be reduced.

Alternatively, the metal layer **103** may be formed by a method by which a solution containing any of the metal materials is applied onto the front surface of the semiconductor substrate **102**. By this method, the concentration of the metal material in the solution can be controlled, which enables the metal layer **103** to be thin. In addition, the metal materials contained in the metal layer **103** can be dispersed homogeneously.

Next, the n^+ region **104** and the p^+ region **106** are formed on the back surface side of the semiconductor substrate **102** (FIG. **2**A).

The n^+ region **104** can be formed by adding an impurity element imparting n-type conductivity (e.g., phosphorus or arsenic) by doping or the like with the use of a mask.

The p^+ region **106** can be formed by adding an impurity element imparting p-type conductivity (e.g., aluminum or boron) by doping or the like with the use of a mask.

Next, an insulating film **107** is formed on the back surface of the semiconductor substrate **102** in which the n^+ region **104** and the p^+ region **106** are formed (FIG. **2**B).

The insulating film **107** is a silicon oxide film or the like and functions as a protective film for the semiconductor substrate **102**. The insulating film **107** can protect the semiconductor substrate **102** when a group of whiskers is formed later.

Next, a group of whiskers **114** formed of a crystalline semiconductor is formed over the metal layer **103** (FIG. **2**B). An example in which crystalline silicon is grown to have whiskers will be described below.

The group of whiskers **114** is formed by a low pressure chemical vapor deposition method (also referred to as an LPCVD method).

The LPCVD method is performed using a source gas containing silicon (the semiconductor material) while heating is performed. The heating temperature is set higher than 550° C. and lower than or equal to the temperature that an LPCVD apparatus and the semiconductor substrate **102** can withstand, preferably higher than or equal to 580° C. and lower than 650° C. In addition, the pressure in a reaction chamber of the LPCVD apparatus is set higher than the lower limit of the pressure that can be held with the source gas supplied and lower than or equal to 200 Pa. Examples of the source gas containing silicon include silicon hydride, silicon fluoride, and silicon chloride; typically, SiH_4, Si_2H_6, SiF_4, $SiCl_4$, Si_2Cl_6, and the like are given. Note that hydrogen may be introduced into the source gas.

Since the group of whiskers **114** can be formed by a vapor deposition method, the semiconductor substrate **102** is not contaminated. For that reason, it can be said that the vapor deposition method is superior to a method of forming an uneven structure by etching the semiconductor substrate **102**.

In such a manner, the structure of the group of whiskers **114**, which is described in Embodiment 1, can be formed.

FIG. **5** is a planar scanning electron microscope (SEM) image of the group of whiskers **114**. As shown in FIG. **5**, crystalline silicon obtained in the above process includes a large number of column-like protrusions or needle-like protrusions. A long protrusion has a length of approximately 15 μm to 20 μm along its axis. In addition to the long protrusions, a plurality of short protrusions exists. Some protrusions have axes that are substantially perpendicular to the metal layer **103**, and other protrusions have axes that are oblique to the metal layer **103**. Note that a titanium film is used as the metal layer **103** in FIG. **5**.

Next, the insulating film **107** formed on the back surface of the semiconductor substrate **102** is removed with hydrofluoric acid or the like.

Next, insulating films **108** are formed on the surface of the group of whiskers **114** and the back surface of the semiconductor substrate **102** (FIG. **2**C). The insulating film **108** is a silicon nitride film or the like and functions as a passivation film.

After that, contact holes are formed in the insulating film **108** formed on the back surface of the semiconductor substrate **102**, whereby the n^+ region **104** and the p^+ region **106** are exposed (FIG. **3**A).

The contact holes can be formed by irradiating the insulating film **108** with laser light, by etching with the use of a mask, or the like.

Then, an electrode **110** and an electrode **112** that are electrically connected to the n^+ region **104** and the p^+ region **106**, respectively, are formed by a screen printing method, an evaporation method, or the like (FIG. **3**B).

Note that the electrode **110** and the electrode **112** can be formed using an element selected from aluminum, silver, titanium, tantalum, tungsten, molybdenum, and copper, or an alloy material or a compound material which mainly contains any of the elements. Alternatively, a stack of these materials may be used.

Through the above process, the photoelectric conversion device can be manufactured.

Note that the metal layer **103** may be removed by gettering. As the gettering, for example, heat treatment is performed at temperatures higher than or equal to 800° C. and lower than or equal to 1150° C. in an oxidizing atmosphere containing a halogen element. Specifically, heat treatment may be performed at 950° C. in an atmosphere containing oxygen and hydrogen chloride at 3%. The metal layer **103** is removed by gettering, which allows the amount of incident light to be increased. Alternatively, the metal layer **103** may be etched with hydrofluoric acid or the like.

This embodiment can be combined with any of the other embodiments as appropriate.

(Embodiment 3)

In this embodiment, an example of a manufacturing method of a photoelectric conversion device, which is different from the manufacturing method described in Embodiment 2, will be described.

In Embodiment 2, the metal layer **103** is formed in a film form on the front surface of the semiconductor substrate **102**.

In contrast, in this embodiment, an island-shaped metal layer is formed on the front surface of the semiconductor substrate **102**, instead of the metal layer **103** illustrated in FIG. **2**A. The island-shaped metal layer may be formed by a screen printing method, an evaporation method, or the like.

Accordingly, in a photoelectric conversion device after manufacture, an island-shaped metal layer **116** is provided between the front surface of the semiconductor substrate **102** and the group of whiskers **114** (FIG. **4**). When the island-shaped metal layer **116** is formed, reflection or the like can be reduced as compared to the case where a metal layer is formed over the entire surface of the semiconductor substrate.

Other steps and the like are similar to those described in Embodiment 2.

This embodiment can be combined with any of the other embodiments as appropriate.

This application is based on Japanese Patent Application serial no. 2010-139799 filed with the Japan Patent Office on Jun. 18, 2010, the entire contents of which are hereby incorporated by reference.

What is claimed is:

1. A method for manufacturing a photoelectric conversion device, comprising the steps of:

forming a metal layer over a front surface of a semiconductor substrate;

supplying a semiconductor gas to the metal layer at a temperature of higher than 550° C. to form a plurality of whiskers over the front surface of the semiconductor substrate;

irradiating a back surface of the semiconductor substrate with an n-type impurity gas to form an n-type impurity region on the back surface of the semiconductor substrate;

irradiating the back surface of the semiconductor substrate with a p-type impurity gas to form a p-type impurity region on the back surface of the semiconductor substrate;

forming a first electrode on the n-type impurity region; and

forming a second electrode on the p-type impurity region.

2. The method for manufacturing the photoelectric conversion device according to claim **1**, further comprising the steps of:

forming an insulating film over the plurality of whiskers.

3. The method for manufacturing the photoelectric conversion device according to claim **1**,

wherein the n-type impurity region contains an n-type impurity element added by a doping method, and

wherein the p-type impurity region contains a p-type impurity element added by a doping method.

4. The method for manufacturing the photoelectric conversion device according to claim **1**,

wherein the metal layer comprises an island structure.

5. The method for manufacturing the photoelectric conversion device according to claim **1**,

wherein the p-type impurity region comprises a first p-type impurity region and a second p-type impurity region, and

wherein a first impurity concentration of the first p-type impurity region is different from a second impurity concentration of the second p-type impurity region.

6. The method for manufacturing the photoelectric conversion device according to claim **1**,

wherein each of the plurality of the whiskers comprises a protrusion with a diameter of greater than or equal to 500 nm and less than or equal to 3 μm, and a length of greater than or equal to 1 μm and less than or equal to 100 μm.

7. The method for manufacturing the photoelectric conversion device according to claim **1**,

wherein a reflectance of the plurality of the whiskers is less than or equal to 0.2%.

8. The method for manufacturing the photoelectric conversion device according to claim **1**,

wherein the metal layer is made of platinum, aluminum, copper, titanium, or an aluminum alloy including silicon, titanium, neodymium, scandium, or molybdenum.

9. A method for manufacturing a photoelectric conversion device, comprising the steps of:

forming a metal layer over a front surface of a semiconductor substrate;

supplying a semiconductor gas to the metal layer at a temperature of higher than 550° C. after forming the metal layer to form a plurality of whiskers over the front surface of the semiconductor substrate;

irradiating a back surface of the semiconductor substrate with an n-type impurity gas to form an n-type impurity region on the back surface of the semiconductor substrate;

irradiating the back surface of the semiconductor substrate with a p-type impurity gas to form a p-type impurity region on the back surface of the semiconductor substrate;

forming an insulating layer on the n-type impurity region and the p-type impurity region;

forming a first electrode on the n-type impurity region electrically connected to the n-type impurity region through a contact hole in the insulating layer; and

forming a second electrode on the p-type impurity region electrically connected to the p-type impurity region through a contact hole in the insulating layer.

10. The method for manufacturing the photoelectric conversion device according to claim **9**,

further comprising: forming an insulating film over the plurality of whiskers.

11. The method for manufacturing the photoelectric conversion device according to claim **9**,

wherein the n-type impurity region contains an n-type impurity element added by a doping method, and

wherein the p-type impurity region contains a p-type impurity element added by a doping method.

12. The method for manufacturing the photoelectric conversion device according to claim **9**,

wherein the metal layer comprises an island structure.

13. The method for manufacturing the photoelectric conversion device according to claim **9**,

wherein the p-type impurity region comprises a first p-type impurity region and a second p-type impurity region, and

wherein a first impurity concentration of the first p-type impurity region is different from a second impurity concentration of the second p-type impurity region.

14. The method for manufacturing the photoelectric conversion device according to claim **9**,

wherein each of the plurality of the whiskers comprises a protrusion with a diameter of greater than or equal to 500 nm and less than or equal to 3 μm, and a length of greater than or equal to 1 μm and less than or equal to 100 μm.

15. The method for manufacturing the photoelectric conversion device according to claim **9**,

wherein a reflectance of the plurality of the whiskers is less than or equal to 0.2%.

16. The method for manufacturing the photoelectric conversion device according to claim **9**,

wherein the metal layer is made of platinum, aluminum, copper, titanium, or an aluminum alloy including silicon, titanium, neodymium, scandium, or molybdenum.

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